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Abstract

NASA and Japan's Institute of Space and Astronautical Science (ISAS) have agreed to cooperate on the first mission to collect samples from the surface of an asteroid and return them to Earth for in-depth study. Known as MUSES-C, the mission will be launched on a Japanese M-5 launch vehicle in January 2002 from Kagoshima Space Center, Japan, toward a touchdown on the asteroid Nereus in September 2003. A NASA-provided miniature robotic rover will conduct in- situ measurements on the surface. The asteroid samples will be returned to Earth by MUSES-C via a parachute-borne recovery capsule in January 2006.

This paper will describe the scope and state of the NASA-ISAS collaboration as well as an overview of the mission design, major system design and operational scenarios. This paper will focus on the non-technical aspects of the international collaboration between NASA/JPL and ISAS. Topics to be discussed will include the differences between NASA/JPL and ISAS. in the following 4 areas: 1) programmatic, 2) institutional, 3)-project development process and 4) culture. Several differences between the US/NASA/JPL and Japan/ISAS are noted, however the similarities at the level of the working, technical engineer or scientist are more important than the differences.

1. Introduction

The Mu Space Engineering Spacecraft (MUSES) C mission[1] is being managed and implemented by the Japanese Institute of Space and Astronautical Science (ISAS). The MUSES C project was formally authorized by the Japanese government in April 1996. The MUSES C project is presently in its prototype model phase and the flight model fabrication will start in 1999. The MUSES-C mission is planned to be the world's first sample return attempt from a near Earth asteroid. The MUSES C project is similar to NASA's New Millennium series of projects; i.e. it has technology demonstration/validation objectives as its primary goals as well as important science objectives. On MUSES C, ISAS will demonstrate the following four technologies: 1) Solar Electric Propulsion for primary propulsion in interplanetary space, 2) Autonomous Guidance and Navigation enabling the spacecraft to make a rendezvous with the asteroid and also to descend and touch-down on the surface for sample collection, 3) Sample Collection technique under the ultra-low gravity field, 4) Direct and hyperbolic reentry from an interplanetary trajectory. The primary target for MUSES C is the asteroid Nereus (4660). The project also has a back-up target, 1989ML, whose launch window is 6 months later than that for Nereus. The mission to Nereus will be launched from Kagoshima, Japan in January 2002 using ISAS's MV launcher. Rendezvous and sampling would take place during April and May 2003 and the re-entry at Earth would be in January 2006. By coincidence, the January 2006 re-entry date is the same month as the re-entry date for NASA's Stardust mission.

NASA and ISAS have agreed in principle to collaborate on the ISAS MUSES C mission for the mutual benefit of both space agencies. Presently, the collaboration includes the following elements in addition to the baseline MUSES C mission. NASA will: 1) build and deliver to ISAS a rover to be used on the surface of the asteroid, 2) provide DSN antenna time for commands, telemetry and navigation, 3) provide navigation support for critical phases of the mission, 4) support the testing and design review of the MUSES C heat shield at facilities of the Ames Research Center, 5) support optical and radio frequency observations of the target in apparitions close to launch, 6) arrange for the recovery of the MUSES C sample capsule on US soil and 7) provide co-investigators for the instruments on the MUSES C spacecraft.

ISAS will: 1) deliver the NASA rover to the asteroid, provide a mission design that enables a scientifically valuable rover mission, 2) provide information on the sampling mechanism, 3) provide a small portion of the sample material to NASA, 4) allow NASA investigators to analyze the sample material with ISAS colleagues in Japan and 5) provide co-investigators for the instruments on the NASA rover.

The MUSES-CN rover mission[2] begins when it is ejected from the MUSES-C spacecraft onto Nereus. Prior to release, the solar-powered rover sits inside the Orbiter-Mounted Rover Equipment (OMRE). While attached to the spacecraft, the rover is shielded from the Sun. The OMRE is the rover's interface to the spacecraft and contains an antenna/ receiver for rover- OMRE communication and a data line for data transfer. The rover will uplink at least 8 Mb of data a day to the spacecraft; these science and engineering data and will be compressed appropriately in consultation with the engineering and science teams. The MUSES-C spacecraft will downlink at least 8 Mb of rover data a day to Earth. Once the rover is dropped from the spacecraft, it is expected to bounce a few times before coming to rest on the surface. It will then orient itself. Due to the low-gravity environment, the maximum speed the rover can travel is about 1.5 mm/sec without losing surface contact. The rover has been designed with the capability to right itself if it flips onto its back. Since the four posable struts are independent, the rover can be commanded to point itself in any orientation. A pointable mirror and actuated focus mechanism allow the rover to take panoramic images as well as microscopic ones.

The collaboration between NASA and ISAS on the MUSES C mission is implemented in the context several "areas" which influence the work of the collaboration. For the purpose of this paper, these "areas" include the following: 1) programmatic, 2) institutional, 3) project development and 4) culture. The remainder of this paper discusses each of these "areas", how they differ in Japan and in the US, and the influence each has on the collaboration between NASA and ISAS on the MUSES C mission. While the remainder of this paper focuses primarily on the differences between ISAS and NASA/JPL, it must be understood, that at the level of the working, technical engineer or scientist the similarities of the Japanese and US individual are much more important than the differences. These similarities include: 1) intelligent, competent, dedicated and hard working people; 2) intellectually not financially motivated organizations; 3) commitment to space exploration; 4) open to learning and respectful of the other's culture and business practices; 5) common physics and engineering laws and 6) common desire to explore and understand the scientific questions associated with space exploration.

2. Programmatic

The programmatic area includes the policy and high level objectives of the agencies and laboratories involved in the collaboration on MUSES C.

The manner in which NASA and ISAS view international collaboration is important. In reference 3 NASA's policy goals for international cooperation are defined as follows: 1) meet NASA programmatic objectives, 2) be mutually beneficial, 3) have scientific and technical merit, 4) be between government agencies, 5) have clearly defined and distinct managerial and technical interfaces, 6) protect against technology transfer and 7) take into account industrial competitiveness.

When the preceding goals of international collaboration are successfully met, then the following benefits[3] are expected to be provided to NASA and the US government: 1) reduced cost to NASA for space activities, 2) access to data and expertise from the international partner, 3) promotion of US foreign policy goals by strengthening relationships between the US and the international partner and 4) global issues can be addressed on a global basis

ISAS's rationale for participating in international collaborations are as follows: 1) meet ISAS programmatic objectives, 2) be compliant with the financial and legal requirements, 3) be mutually beneficial in terms of science and technology, 4) provide the operation viability and the relaxed operations burdens and 5) nurture or expand the Japanese science and technology community,

When the collaboration is found contingent upon the criteria above, ISAS and the Japanese government expect the following benefits: 1) enhanced science output within the cost requirement, 2) flexible and viable operations environment, 3) access to data and expertise from the international partner and 4) promotion of ISAS partnership with the foreign space science organizations.

NASA and ISAS also have other differences beside those of strategic outlook. One very simple difference is the start of the fiscal year in the US government is October and the start of the fiscal year in the Japanese government is April. This difference is usually not a problem, however it does mean that the two governments, space agencies and the MUSES C and MUSES CN projects are never entirely synchronized with respect to the financial cycle and those decisions that are dependent upon the budget cycle cannot always be made at the same time.

Another difference between NASA and ISAS is the process used to plan new missions. Relative to the process used in ISAS, the NASA process is more uncertain, and less predictable. New projects at ISAS are usually studied for few years then proposed to the ISAS Science or Engineering Committee and finally proposed to the government. Many new NASA missions are now the result of a competition process that is open to any university person in the US. The result of this competition is not known until a short time before the project must be implemented which leaves essentially no time to form international collaborations unless it was done during the proposal process which international partners are reluctant to do because the result of the competition is very hard to predict. In the case of the collaboration on MUSES C, ISAS had been authorized to proceed with MUSES C before the first discussions of collaboration. Due to the nature of the proposed collaboration, a competition within NASA was not required.

A final difference, which is related to the second, is the degree of commitment each government and space agency makes to a project be it international or not. The Japanese government is very good at sticking to their commitments. In the US, the government essentially begins each year all over again and any project from the previous year may not receive support and can be cancelled. NASA has had to cancel projects due to this process. It is very unusual for the ISAS and the Japanese government to ever cancel an authorized project. Since the ISAS MUSES C project is already authorized by the Japanese government, and the NASA MUSES CN project is quite small, it is anticipated that both projects will proceed without any threat of disruption from the governments.

3. Institutional

In the context of this paper, the institutional area means the organization and functions of the laboratories where the MUSES C and MUSES CN projects are being implemented. Because the work of the MUSES CN project is being implemented at JPL, the institutional aspects of JPL, rather than NASA, will be discussed.

Both ISAS and JPL were started as laboratories within prestigious universities. ISAS started within the University of Tokyo and JPL with the California Institute of Technology. As the business of space exploration grew, both ISAS and JPL outgrew the physical environment and most of the organization aspects of their parent universities. Today, while all people working for JPL are employees of the California Institute of Technology, few other ties remain to the original university environment. At ISAS, the principle people hold the title of professor or assistant professor and many students work at there. While closer to their university origins, the people at ISAS are employees of the government specifically the Ministry of Education, Science, Sports and Culture. The difference to note is that the ISAS MUSES C project people are employees of the government, like NASA people, while the JPL MUSES CN project people are employees of a private university more similar to a private company than government employees.

JPL is a large laboratory [~6000 people] with an annual budget somewhat larger than $1000M. Most, but not all the work done at JPL is for NASA. About 15% of JPL's work is done for the US Department of Defense. JPL's work for NASA includes the majority of the Solar System Exploration program, small portions of the Earth Science program, a growing share of the Astrophysics program and a large percentage of NASA's R&D on space technology as well as running the entire NASA Deep Space Network. Presently JPL has 5 major [total cost of ~$200M each] and many ~15 smaller [total cost of ~$20M each] projects under development. JPL has all the necessary people and facilities to design, build, assemble, test and operate major space projects. JPL also implements many projects with a system contractor who does all the spacecraft work. ISAS is a smaller laboratory [~400 people] with about 80 full and associate professors, 25 visiting professors, 60 research associates, 162 technical and administrative staff [majority are administrative] and 100 students [nearly all graduate students]. The ISAS annual budget is about $200M where most of the work is done for space science, little for Earth science or technology and no work is done for the Japanese military. Unlike JPL, ISAS does develop its own launch vehicles. Usually, ISAS has only 1 or two projects in the flight model phase simultaneously. Contractors perform all of ISAS's flight hardware work although the final system testing and operations are performed at ISAS.

In the context of the collaboration on MUSES C, the important aspects of the preceding sentences is that JPL has the "in house" expertise for nearly any aspect of the collaboration, while ISAS is dependent upon their contractors for many important issues. Also, because there are many people at JPL, most people have a single assignment and JPL management expects people to focus

on one job at a time i.e., the JPL MUSES CN project manager is not expected to work on other projects. At ISAS, because there are relatively so few people, everybody has several assignments and is contributing to several projects simultaneously, i.e. the ISAS MUSES C project manager does work on other projects.
A small but important difference between JPL and ISAS is that although JPL has approximately ten times more staff than does ISAS, approximately ten times more ISAS staff visit JPL for long term visits than the other direction. This difference means that, in general, ISAS people know much more about what JPL is and what it does, than JPL people know about ISAS. This difference is apparent on the MUSES C collaboration.

Even with the differences noted above, both ISAS and JPL are the world class space science laboratories, where solar system exploration missions are conceived and implemented in a fiscal environment of stable or declining budgets. Nearly all of the technical aspects of the work are identical which is not surprising since physics is the same at JPL and ISAS

4. Project Development Processes

There are some differences is the project development process at ISAS and JPL which are important to the collaboration on MUSES C. NASA expects all projects to be "better, faster, cheaper" which means that projects should be ready for launch 3 years after authorization. ISAS has a 5-year project development process. The ISAS project period is 5 to 6 years due to the small size of spacecraft market in Japan. The spacecraft fabricators start a specific development, once the financial authority endorses the project. The two-year prototype phase is used to develop the necessary technology for the mission. If the project did not have the prototype phase, the spacecraft technology would rely on the existing technology, which is often not suitable for the ISAS missions.

The MUSES CN project must follow the schedule of the MUSES C project for functions like integration and test with the spacecraft. In general the MUSES CN project from authorization to launch will be longer than it would be if it were a NASA only project. Being longer means that the MUSES CN project will be somewhat more expensive than it would be if it were a NASA only project.

ISAS uses a contractor to build the MUSES C spacecraft. The relationship between ISAS and its contractor is not a simple customer and prime contractor relationship as it is commonly used in the US. The relationship is more of a partnership where ISAS retains the prime responsibility for design, I&T [final system I&T is performed at ISAS] and operations, but the contractor is a heavily involved support contractor for many but not all the spacecraft subsystems. The contractor also has personnel that know the launch vehicle, launch site, tracking site and operations center very well and are able to supply these support services efficiently and enable the ISAS personnel to concentrate on the innovative design aspects of new hardware. This partnership works very well and enables ISAS to depend on their contractor much more than JPL could with a typical system contractor.

Another important difference between ISAS and JPL in the project development process is that for JPL projects, the amount of money authorized for the project is extremely important and the MUSES CN project is not free to do new things that would cost more money. In the era of "better, faster, cheaper", NASA/JPL projects are strongly discouraged from exceeding their authorized budget. The ISAS MUSES C has an authorized budget, however it is not watched as closely as the JPL MUSES CN budget and ISAS has more ability to ask its contractors to compensate for problems and additional work that must be added.

At JPL the project manager is "king" has a great amount of freedom to implement the project. As mentioned above, the JPL project manager is not expected to contribute to other projects, but should spend all his time on a single project. With this freedom comes the responsibility to implement the project for the authorized budget. At ISAS, as noted above, most people contribute to several projects so the MUSES C project manager contributes to other projects and in return has other people to contributing to MUSES C. The leadership of MUSES C is somewhat less focused on one person compared to the MUSES CN project management at JPL.

5. Culture

In addition to the discussion on the programmatic, institutional and project development process differences, culture and language are other areas, which influence the collaboration between the ISAS MUSES C and JPL/NASA MUSES CN projects. Language is probably the most noticeable difference. Fortunately, the Japanese participants speak, read, write and understand English very well. The capability of the ISAS people in English is essential to the collaboration, since the NASA/JPL participants have no capability in the Japanese language. This difference in language skills is a factor in the collaboration activities. It is an advantage for the ISAS people to understand English and a disadvantage to the NASA/JPL people not to understand Japanese. All of the business of the collaboration is performed using English, although there are many MUSES C project documents and meetings which are prepared only in Japanese, which means that the MUSES CN project cannot have a complete understanding of the MUSES C project.

There are many cultural differences beyond language that can effect the collaboration on MUSES C. Reference 5 is a good source for understanding the cultural differences between Japan and the US in business collaborations such as the MUSES C collaboration. Table 1 is a summary of the general differences between Japanese and US cultures based upon 9 cultural variables according to such sources as reference 4. Generally the dominant business culture in the US is individual, action, linear based while that in Japan is more based upon the group, relationships and order. Even a casual discussion of these cultural differences and their effect on the MUSES C collaboration is far beyond the scope of this paper. However, it is useful to understand that differences, problems and misunderstandings can be culturally driven. Cultural driven issues can be difficult to resolve and sometimes it is even difficult to recognize that the origin of an issue is cultural rather than technical. Patience and a respect for others are important behaviors when faced with culturally driven issues.

Table 1

Cultural Variable	**Cultural Orientation**	
	US	**Japan**
Environment	The environment can be controlled	People/actions should be in harmony
Time	Sequential/linear	Simultaneous tasking
Action	Action is more important	Relationships are more important
Communications	Information is transmitted predominately by the explicit words	Information is transmitted by the words and context and is often more implicit
Power	Power is decentralized, equality is emphasized	Power is centralized, hierarchical organization is emphasized
Individualism	Promote individual identity	Promote group identity
Competitiveness	Competitive	Competitive
Structure	Flexibility is promoted	Order is promoted
Thinking	Linear, problems are approached one step at a time	Systematic, problems are approaches as a whole

6. Summary

ISAS and NASA are committed to collaboration on the ISAS MUSES C asteroid sample return mission. The mission will be launched to the asteroid Nereus in January 2002 and will return to Earth in January 2006. The collaboration has been structured to be mutually beneficial to both partners. ISAS will deliver to the asteroid a small NASA/JPL rover, in return for which ISAS will receive, DSN, navigation and test support from NASA. NASA will arrange for the recovery of the MUSES C sample return capsule, in return for which NASA will receive a portion of the asteroid sample material. Both NASA and ISAS will admit scientists from the other agency to participate in their science experiments. This paper discussed this collaboration as well as 4areas, which effect the collaboration. These 4 areas are: 1) programmatic, 2) institutional, 3) project development process and 4) culture. Several differences between the US/NASA/JPL and Japan/ISAS were noted in the context of these environments. It was also noted that the similarities at the level of the working, technical engineer or scientist the similarities of the Japanese and US individual are much more important than the differences and that the ISAS/NASA collaboration on the MUSES C mission is well on its way to being a successful partnership for both sides and for the world as a whole.

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